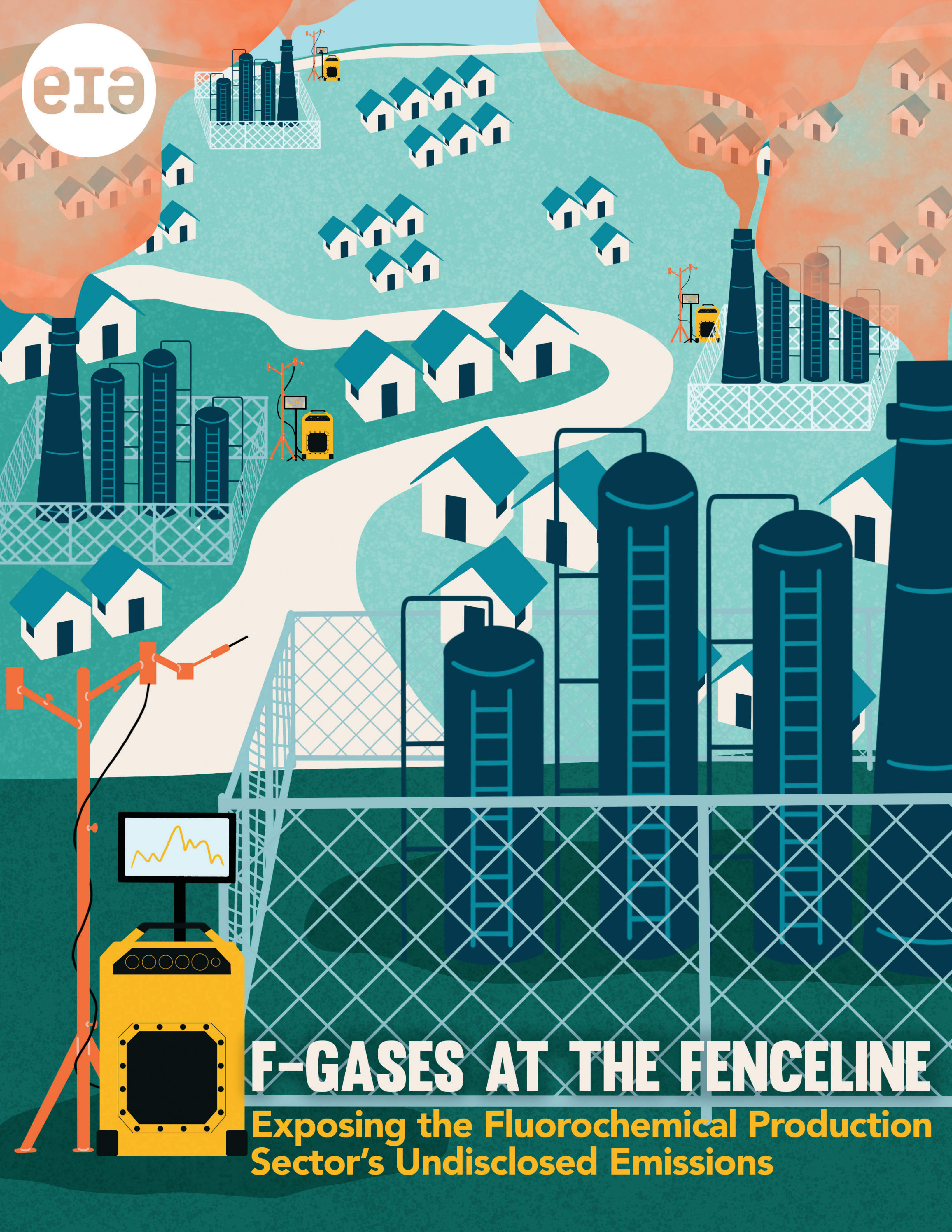


F-GASES AT THE FENCELINE

Exposing the Fluorochemical Production Sector's Undisclosed Emissions

Table of Contents

Link to Supplementary Material:

EIA acknowledges and thanks Dr. Masoud Ghandehari, Professor and Director, Doctoral Studies in Urban Systems at New York University’s Tandon School of Engineering for providing significant insight and expertise in reviewing the EIA approach, methodology, and analysis for this report.

Environmental Investigation Agency (EIA) is an independent non-profit campaigning organization dedicated to identifying, investigating, and implementing solutions to the world’s most pressing environmental problems. Our campaigns to protect endangered wildlife, forests, and the global climate operate at the intersection between increasing global demand and trade and the accelerating loss of natural resources and species. We reduce the impact of climate change by campaigning to eliminate powerful greenhouse gases and improve energy efficiency in the cooling sector, and exposing related illicit trade. We use our findings to campaign for new legislation, improved governance, and more effective enforcement. Information in this report regarding the facility production activities and reported emissions is based on best available public information.

Fenceline view of the Honeywell facility, Baton Rouge, Louisiana.

Introduction

Fluorochemicals have been the primary driver of ozone depletion over the last century, and continue to cause climate and toxic pollution to this day. Despite the global agreement to control many of these substances under the Montreal Protocol, there is now an alarming trend of their unexpected rising emissions. Avoidable releases of these gases during their production may be an overlooked and significant contributor to such emissions. These include some of the most potent greenhouse gases and ozone depleting substances (ODS) known to humankind.

This report presents an investigative case study using portable infrared spectroscopic gas detection to demonstrate fenceline monitoring of emissions at fluorochemical production facilities. Infrared spectroscopy is a well-established scientific approach to identifying and monitoring chemical substances that so far has had limited application in targeted monitoring of emissions of fluorinated gases

EIA detected numerous F-gases near the fenceline at two production facilities in the United States, including various hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), and hydrofluoro-olefins (HFOs).

(F-gases).[1,2] EIA detected numerous F-gases near the fenceline at two production facilities in the United States, including various hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), and hydrofluoro-olefins (HFOs). **Several of the CFCs and HFCs detected have not been reported by the Honeywell facility in recent years of mandatory greenhouse gas and toxic substances reporting, suggesting that the company may be unaware of the emissions or failing to report them.** This demonstrates the considerable need to strengthen monitoring, verification, and enforcement (MRV&E) mechanisms, particularly of emissions from fluorochemical production.

Recently published atmospheric research findings have also estimated unexpected emissions of approximately 870 million tonnes CO_2 equivalent ($MtCO_2e$) on an annual basis in recent years (see Figure 1) of F-gases and other related substances controlled under the Montreal Protocol. These emissions show significant linkages with legal production processes, including production uses as feedstocks that are exempted under the Montreal Protocol, as well as cases of proven illegal production and non-compliance with treaty obligations.

The unexpected emissions of globally phased out ODS, notably CFC-11, which were attributed to illegal production and use,[3] also demonstrate that improvements to the Montreal Protocol's MRV&E regime are necessary to ensure the sustained phase-out of gases controlled under the Protocol.

The unexpected CFC-11 emissions could have been potentially identified and mitigated earlier had more targeted monitoring been in place.

It is increasingly clear that emissions from production facilities are significant and not sufficiently quantified, tracked, and controlled. Inadequate transparency regarding data on production combined with gaps in monitoring and verification has resulted in these avoidable emissions being shrouded in relative obscurity.

The international community and fluorochemical producer countries, must improve regulatory controls, reporting, and monitoring of production processes and their emissions. Finally, given the upstream emissions from feedstock production for making HFOs and concerns about future ecological and potential toxic effects from persistent by-products, reliance on fluorinated substances should be eliminated across all sectors regardless of direct climate warming impacts, where alternatives are available or their use is non-essential.

EIA investigator setting up detection equipment outside of Honeywell, Baton Rouge.

Key Findings

The below findings are based on EIA field sampling at two U.S. fluorochemical production facilities in 2022 and 2023. These results underscore the need for concerted action to monitor and mitigate avoidable industrial emissions from the production of fluorochemicals.

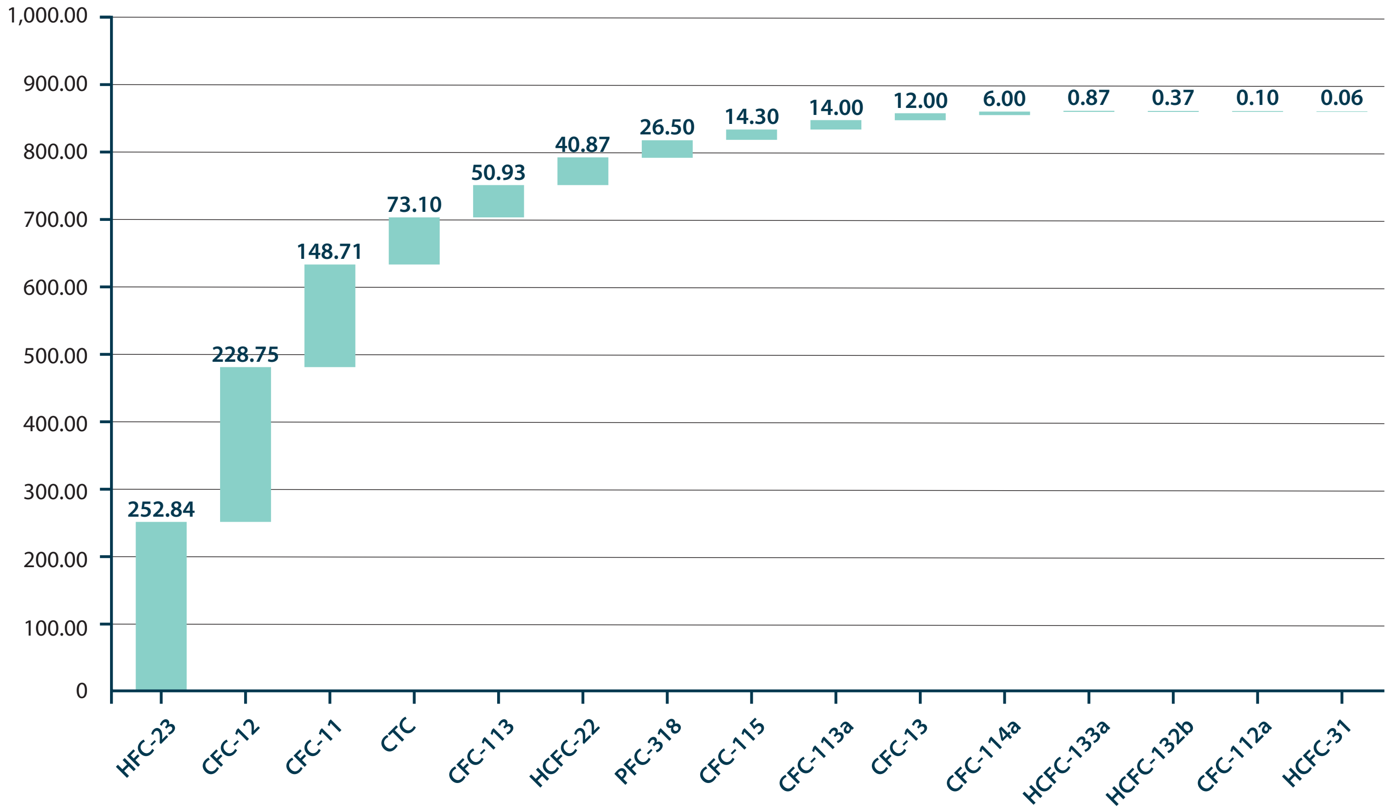
- Sampling and analysis of air near two production facilities operated in the United States by two major fluorochemical producers **detected an array of fluorinated gases** which are known to have potent global warming potentials (GWPs), and/or ozone depletion potentials (ODPs).
- Multiple substances detected in this case study are associated with rising global emissions identified in recent atmospheric studies that link fluorochemical production and/or illegal production and use as the primary source of approximately 870 million tonnes CO_2 equivalent in emissions on an annual basis (See Figure 1).
- At one production facility operated by Honeywell International in Baton Rouge, Louisiana, **three different types of CFCs were detected:** CFC-13, CFC-113 and CFC-114. These are ODS with high GWPs ranging from 6,520 to 16,200 that are **banned globally**, except when used as feedstocks or process agents to produce other chemicals. The facility reported CFC-13 emissions in 2017-2018, but reported zero emissions for 2019-2021. Reported data for CFCs in 2022 and 2023 when detection took place are not yet reported/available publicly for this facility at the time of publication. **CFC-113 and CFC-114 have been consistently reported by the facility and reported CFC emissions have been increasing in recent years.**
- **A suite of HFCs were also detected** at the Honeywell, Baton Rouge facility some of which were not reported by the facility in mandatory greenhouse gas reporting from 2018-2022 (US GHGRP). HFC-125 and HFC-143a, detected by EIA in 2022, were not reported by the facility in 2022. HFC-32 and HFC-134a, detected in 2023, were not reported in earlier years of reporting from 2018-2022. It is not clear why these chemicals are being detected yet absent from facility reporting.
- **HFOs and a hydrochlorofluorolefin (HCFO) were also detected** at the Chemours and Honeywell facilities. HFO-1234yf was detected at a Chemours facility in Corpus Christi, Texas, and HCFO-1233zd and HFO-1234ze were detected at the Honeywell, Baton Rouge facility; in each case these HFOs are end products manufactured at the respective facilities. While these HFOs have low direct climate impacts, they are considered per- and poly- fluoroalkyl substances (PFAS) and can degrade into persistent by-products. HFO-1234yf in particular produces high yields of trifluoroacetic acid (TFA). TFA is a strong acid that can be toxic to aquatic organisms, plants, and humans.
- Technologies exist to **scale up targeted monitoring of emissions** from all fluorochemical production facilities.

Atmospheric Findings: Rising Unexplained Emissions

Recent scientific findings point to a shocking array of new and unexpected rising global emissions associated with fluorochemical production, illegal production and use, and unexplained sources. Atmospheric measurements show rising emissions of various chemicals that are either used in fluorochemical production or are by-products of it, including HFC-23, various CFCs and hydrochlorofluorocarbons (HCFCs), perfluorocyclobutane (PFC-318), and carbon tetrachloride (CTC). The sources of these emissions remain uncertain after accounting for known estimates, but the majority of these substances are linked to production processes, as feedstocks, chemical intermediates, or by–products.

Figure 1 below displays recent scientific estimates of unexpected emissions of F-gases and other associated substances, most of which are controlled under the Montreal Protocol.[4] **Taken together, these studies link approximately 870 million MTCO$_2$e of annual emissions to fluorochemical production processes, illegal fluorochemical production and use, or other unexplained and unexpected sources.** This is equivalent to more than 200 coal fired power plants, and approximately equal to the annual emissions of Germany.[5]

Figure 1: Scientific Findings on Unexpected Emissions Linked to Production, Unknown Sources, and Illegal Production and Use*



Chemical	WMO 2022 GWP	Estimated Emissions (Gg/yr)	Estimated Emissions (Million Tonnes CO$_2$e/yr)	Year(s) Observed	Description of Emission Sources	Reference
HFC-23	14,700	17.20	252.84	2019	Top-down estimate of global emissions. By-product emissions from production of HCFC-22, as well as from pyrolysis of HCFC-22 to produce TFE and HFP. Potential by-product emissions from production of HFC-32, HFC-125 and other controlled substances. Also includes emissions from banks of niche refrigerant and fire suppression uses.	WMO (2022)[6]
CFC-12	12,500	18.30	228.75	2014-16	Top-down estimate of unexpected emissions excluding emissions from banks. Emissions are linked to illegal production and use or other unknown sources.	Lickley et al. (2021)[7]
CFC-11	6,410	23.20	148.71	2014-16	Top-down estimate of unexpected emissions excluding emissions from banks. Emissions are linked to illegal production and use or other unknown sources.	Lickley et al. (2021)[8]

Chemical	WMO 2022 GWP	Estimated Emissions (Gg/yr)	Estimated Emissions (Million Tonnes CO_2e/yr)	Year(s) Observed	Description of Emission Sources	Reference
CTC	2,150	34.00	73.10	2020	Top-down estimates of global CTC emissions are 44 ± 15 Gg/yr from 2016 and 2020. Once legacy emissions from landfills and contaminated soils (5-10Gg) are subtracted, total emissions from production and unexplained sources are 44 - 10 = 34Gg. Unexplained emissions are assumed to be from feedstock and chloromethane production or other unknown sources. CTC is a feedstock to various CFCs, HFCs, HFOs, and chloroform, which is used to make HCFC-22.	WMO (2022) (Update to Sherry et al. 2018)[9]
CFC-113	6,530	7.80	50.93	2014-16	Top-down estimate of unexpected emissions excluding emissions from banks. CFC-113 is a common feedstock used to make HFC-134a, TFA, pesticides and chlorotrifluoroethylene (CTFE) which is a precursor used to make fluoropolymers.	Lickley et al. (2021)[10]
HCFC-22	1,910	21.40	40.87	2019	Bottom-up estimate of emissions from feedstock production and use. Feedstock to TFE/HFP to produce PTFE and other fluoropolymers.	WMO (2022)[11]
PFC-318	10,600	2.50	26.50	2020	Top-down estimate. By-product of hexafluoro-propylene (HFP) production, which is used to make fluoropolymers including PTFE (aka Teflon).	WMO (2022)[12]
CFC-115	9,630	n/a	14.30	2020	Top-down estimate of global emissions. No significant banks from end uses. By-product of HFC-125 production.	Western et al. (2023)[13]
CFC-113a	3,930**	n/a	14.00	2020	Top-down estimate of global emissions. No significant banks from end uses. Feedstock/By-product in HFC-125, HFC-134a, HFO-1334mzz production; feedstock in production of TFA and pesticides.	Western et al. (2023)[14]
CFC-13	16,300**	n/a	12.00	2020	Top-down estimate of global emissions. Unknown sources. Potential use as a feedstock for CFC-11, however emissions have not declined in recent years with CFC-11 emissions.	Western et al. (2023)[15]
CFC-114a	7,410**	n/a	6.00	2020	Top-down estimate of global emissions. No significant banks from end uses. Feedstock/ intermediate in production of HFC-125 and HFC-134a.	Western et al. (2023)[16]
HCFC-133a	378	2.30	0.87	2016-19	Top-down estimate of global emissions. No known dispersive end-uses or banks. Feedstock to produce HCFC-123, CFC-113a.	Vollmer et al. (2021)[17]
HCFC-132b	332	1.10	0.37	2019	Top-down estimate of global emissions. No known dispersive end-uses or banks. Likely by-product of HFC production.	Vollmer et al. (2021)[18]
CFC-112a	3,550**	n/a	0.10	2020	Top-down estimate of global emissions. No significant banks from end uses. Unexplained, previous uses as a solvent and feedstock in fluorovinyl ether production.	Western et al. (2023)[19]
HCFC-31	85	.71	0.06	2016-19	Top-down estimate of global emissions. No known dispersive end-uses or banks. By-product of HFC production.	Vollmer et al. (2021)[20]
TOTAL			**869.40**			

*This figure aggregates estimated annual emissions of substances linked to fluorochemical production processes, unexplained sources, and illegal production and use, from published sources. The citations provide quantification of emissions based on either top-down atmospheric findings or bottom-up estimates. All information is based on most recently available published sources.

**Author used GWPs from Hodnebrog, Ø. et al. Updated Global Warming Potentials and Radiative Efficiencies of Halocarbons and Other Weak Atmospheric Absorbers. Reviews of Geophysics 58, 7 e2019RG000691 (2020).

HFC-23: HFC-23 is a potent climate warming gas with a high GWP of 14,600. It is primarily produced as a by-product of HCFC-22 production, which is itself used to make various fluorocarbons and fluoropolymers, including Teflon. Production of HFC-125, HFC-134a, HFC-143a, and possibly some steps of HFO production processes, can also result in by-production of HFC-23.[21] HFC-23 may also be a degradation product of some HFC-based refrigerants, such as R-466A.[22]

Despite a global agreement for the mandatory capture and destruction of HFC-23 by-product under the Kigali Amendment, global HFC-23 emissions have reached the highest levels in history in recent years.

Despite a global agreement for the mandatory capture and destruction of HFC-23 by-product under the Kigali Amendment, global HFC-23 emissions have reached the highest levels in history in recent years.[23] The Montreal Protocol's Scientific Assessment Panel (SAP) estimated global emissions in 2019 to be 17,200 ± 800 tonnes/yr, eight times greater than the expected 2,200 tonnes/yr based on reported activities to capture and destroy by-product emissions as required.[24] In 2020, HFC-23 contributed 15% of the total radiative forcing and 20% of the total emissions from all HFCs.[25] Recent findings show rising HFC-23 emissions from Eastern China contrary to emission reduction activities reported to the Montreal Protocol.[26] Eastern China accounted for at least ~50% of these global HFC-23 emissions and global emission variations closely reflect those measured in Eastern China.[27] More information is needed to pinpoint all sources of the rising emissions.

CFCs and HCFCs: Emissions of at least seven CFCs, ODS with GWPs of up to 16,200 that have been banned for emissive end uses for decades, are continuing to rise, including CFCs-113, 113a, 112a, 114, 114a, 115, and 13.[28, 29] These compounds are linked to production of HFCs-125 and -134a, HFO-1334mzz, CTFE used in making fluoropolymers, and fluorovinyl ether. New emissions of several HCFC molecules with no known end-uses have also been recently identified (HCFC-132b, HCFC-133a, and HCFC-31), and have followed a rising trend over the past two decades.[30] Although most of these substances have known applications in fluorochemical production, emissions sources for several remain unexplained or poorly understood.

PFC-318: Perfluorocyclobutane or c-C4F8 (PFC-318) is a long-lived greenhouse gas with a potent GWP of 10,200. Emissions of PFC-318 are rising sharply, having more than doubled since the early 2000s, reaching 2,200 tonnes in 2017 and 2,300 tonnes in 2020.[31] PFC-318 is a known by-product from the use of HCFC-22 as a feedstock in making polytetrafluoroethylene (PTFE), HFC-125, HCFC-225, and HFO-1234yf. These emissions are highly correlated with HCFC-22 feedstock use.

CTC: CTC is an ODS with a GWP of 2,200 that is still widely used as a feedstock in the production of HFCs and HFOs. Global CTC emissions were on average 44,000 ± 15,000 tonnes/yr in both 2016 and 2020,[32] while the most recent bottom-up estimates are 25,000 tonnes/yr.[33]

Fluorochemical Sector Background

Human and Environmental Impacts

The harmful impacts of fluorochemicals on health and the environment are extensive and multifaceted. Ozone depletion caused by several classes of F-gases has contributed to an increase in excess skin cancer cases, even with their phase-out under the Montreal Protocol.[34] Many fluorochemicals are potent greenhouse gases with GWPs up to tens of thousands of times more potent than carbon dioxide. Fluorinated gases are the fastest growing source of greenhouse gases globally.[35] Finally, the accumulation of persistent fluorinated molecules is an increasingly pressing concern for human and ecosystem health. The strength of the fully fluorinated carbon bond makes these man-made compounds so long lasting that they are referred to as "forever chemicals".

Types of Fluorochemicals and Uses

There are thousands of unique synthetic fluorochemical products with hundreds of applications spanning many sectors. Broadly, fluorochemicals can be classified into three types: fluorocarbons, fluoropolymers, and other specialty or inorganic products (see Figure 2).

Fluorocarbons include CFCs, HFCs, and HFOs, which represent about 30% of the fluorochemical market (see Figure 3).[36] CFCs and HCFCs are being phased out due to ozone depletion and HFCs are now being phased down under the 2016 Kigali Amendment to the Montreal Protocol due to their potent climate impacts.[37]

HFOs are the fourth generation of fluorocarbons introduced to replace HFCs. Although HFOs themselves have low GWPs, their production requires the use of ozone depleting and/or climate warming fluorochemicals, contributing to production related emissions. Most HFCs and HFOs are also considered PFAS according to widely accepted definitions[38] and some break down into persistent molecules, including TFA. TFA is a strong acid that can be toxic to aquatic organisms, plants, and humans. A recent review of PFAS by the United Kingdom identifies TFA as a potential concern for developmental toxicity.[39] Rising levels of TFA have been detected in Arctic ice cores, indicating increasing accumulation since the introduction of HFC alternatives in the early 1990s.[40] While atmospheric breakdown of some HCFCs and HFCs produces TFA, common HFOs yield much higher levels of TFA. HFO-1234yf, the most widely used HFO for refrigerant uses, yields 92-100%. TFA levels have risen exponentially in various bodies of water globally from the western U.S. to China.[41]

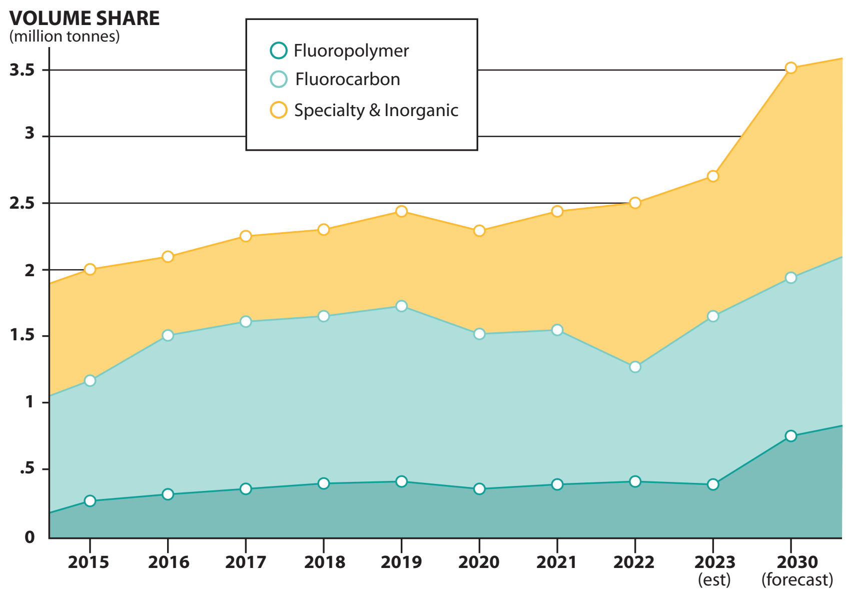
Figure 2: Types and Uses of Fluorochemical Products (Non-exhaustive)[42]

	Types of Fluorochemical Products	Products/Uses	Sectors
Fluorocarbons	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Hydrofluorocarbons (HFCs) Hydrofluoro-olefins (HFOs) hydrochlorofluoro-olefins (HCFOs)	Refrigerants Heat transfer fluids Foam blowing agents Fire suppressants Aerosol propellants Solvents Feedstocks	Refrigeration and air conditioning Automotive/transport cooling Electrical and semiconductors Textiles and chemicals Medical Fluoropolymer production
Fluoropolymers	Polytetrafluoroethylene (PTFE) Polyvinylidene fluoride (PVDF) Polychlorotrifluoroethylene (PCTFE) Fluoroelastomers Others	Coatings Fire suppressants Binders Insulation Mechanical components Laboratory instruments	Cookware Textiles EV Batteries/automotive Medical Aerospace Energy Semiconductors
Specialty and Inorganic/Other	Ethyl difluoroacetate 2,6-dichloro-4-trifluoromethyl aniline Benzotrifluoride 3,4-difluoronitrobenzene Potassium fluoride Calcium fluoride Sodium fluoride Ammonium bifluoride Potassium fluoroborate Ammonium fluoride Others: hydrofluooethers (HFEs)	Fluoroplastics Pesticides/fungicides Non-polar solvents Catalysts Lubricants Stabilizers Etching Surfactants	Aluminum Steel Pharmaceuticals/medical Research Agriculture Electronics Ion-exchange membranes

Fluoropolymers, which are fluorocarbon-based polymers with multiple carbon-fluorine bonds, are most commonly used as coatings and fire suppressants among other uses. They include some of the most well-known PFAS, such as: polytetrafluoroethylene (PTFE, well-known by the brand name Teflon), perfluorooctane sulfonic acid (PFOS), and perfluoro-octanoic acid (PFOA).[43] As of 2020, PTFE and polyvinylidene fluoride (PVDF) made up 55% and 20% of the fluoropolymer market segment respectively, representing the majority of this segment.[44] The market share of PVDF is forecast to increase to 46% by 2030 due mainly to use in the expanding electric vehicle (EV) sector as a binder material for electrodes in EV batteries.[45] Many fluorocarbons are produced as feedstocks or intermediates to produce fluoropolymers or other specialized fluorochemical products.

Specialty and inorganic products make up the largest share, with rising demand in the agriculture and pharmaceutical industries driving growth for this market segment, which represents about 56% of the overall fluorochemical market[46] and are used in industrial processing of aluminum, nuclear fuel, and gasoline and the synthesis of pharmaceuticals, solar panels, lithium-ion batteries, rocket fuel, semi-conductors, LCD screens, and more.

Figure 3: Market Share by Type of Fluorochemical Products[47]



Fluorochemical Market: Volume in Kilo Tons, by Product, 2015-2030

Box 1: Fluorochemicals as 'PFAS' or Forever Chemicals

Another important distinction in classifying fluorochemicals and their impacts is based on their chemical properties as persistent and/or bioaccumulative substances with human, and environ-mental, health and toxicity concerns. More than 12,000 fluorinated chemicals are considered PFAS[48] when defined as a class of chemicals having one (per-) or more (poly-) fully fluorinated carbon-fluorine (CF2 or CF3) bonds.[49] This is the policy and scientific definition of PFAS widely followed by the Organization for Economic Cooperation and Development (OECD),[50] European Union,[51] and several U.S. states such as California[52] and Maine.[53] Failure to regulate PFAS as a broad class of substances has prevented a transition to safe alternatives. This has led to recent calls to adopt broad upstream controls on PFAS as a class of substances, resulting in a recent proposal put forward by the European Chemicals Agency (ECHA) which covers more than 10,000 substances, including fluorocarbons such as HFCs and HFOs.[54]

Failure to regulate PFAS as a broad class of substances has prevented a transition to safe alternatives.

Global Production Trends

Global fluorochemical production is currently estimated at over 4.6 million tonnes annually.[55] China is the largest global producer of fluorocarbons and fluoropolymers followed by the U.S., Japan, the European Union, and increasingly in India (see Figure 4).

China's production of HFCs has grown rapidly in recent years reaching 1.4 billion tonnes CO_2e in 2022.[56] The U.S. by comparison, having begun to implement the HFC phasedown, has issued 344 million tonnes CO_2e in production allowances for HFCs for the year 2023.[57] Although production of fluorocarbons has declined in the United States over the past two decades, the U.S. continues to produce a significant quantity of HFCs for domestic use and export, and has rapidly expanded production capacity for HFOs as HFC replacements.[58] The two facilities highlighted in EIA's case study are the sites of continued HFC production and new capacity for HFOs, which has been ramping up since 2018.[59, 60]

Although production of fluorocarbons has declined in the United States over the past two decades, the U.S. continues to produce a significant quantity of HFCs for domestic use and export, and has rapidly expanded production capacity for HFOs as HFC replacements.

Figure 4: Map of Fluorocarbon Producing Countries[61]

Countries that have reported production of ODS or HFCs through Article 7 or Country Programme data.

EIA Investigative Case Study: Production Facility Emissions Monitoring

Methodology Overview

In order to detect F-gas emissions near production facilities, EIA used the Gasmet GT-5000 Terra Portable FTIR Gas Analyzer (the Gasmet), an infrared spectroscopy instrument which measures the absorption of infrared light at different wavelengths of a sampled gas. Every molecule absorbs infrared light in a unique way and therefore measuring the absorbance of infrared energy across different frequencies (called an absorbance spectrum), identifies an "infrared fingerprint" for any molecule as well as the concentration of a substance.[63]

EIA collected air samples from detection locations 650 to 850 feet downwind of production facilities. Sampling measurement sessions consisted of at least 30 minutes of 60-second air samples taken in the same location. EIA conducted several measurement sessions per facility to confirm presence of greenhouse gases and other substances of interest.

Air samples were analyzed with Calcmet Expert, the companion software for the Gasmet device, which can detect and distinctly quantify up to 50 gases simultaneously in real time.[64] Ambient air substances (water vapor, carbon dioxide, methane, and nitrous oxide) were subtracted from the samples, and the residual spectra/"fingerprints" were identified in Calcmet Expert using a library of reference spectra for over 400 substances. The identification of gases in air samples were verified by comparing the reference spectrum for each gas to the sample

(Clockwise): Observing Gasmet detection readings in the field; Gasmet probe extended on pole, collecting air readings; Gasmet device and equipment for maintaining stable baseline for data collection.

spectrum.[65] The selected reference spectra were scaled to correspond with the detected concentration identified in Calcmet Expert, then added together (the mix) and compared with the sample spectrum (the sample) (see Figure 6). The presence of a gas was verified if the combined reference spectra closely matched the sample spectrum and each of the scaled reference spectra were higher than the calculated noise level. (For a detailed reference spectra and sources, please see Supplementary Material, Annex 1).

Facility Profiles and Emissions Reporting

U.S. facilities producing F-gases are subject to mandatory self-reporting of emissions of HFCs, among other gases, under Subparts L and O of the EPA's Greenhouse Gas Reporting Program (GHGRP). Emissions of CFCs, HCFCs, and CTC are reported separately under the Toxics Release Inventory (TRI). (Further details and analysis on required reporting and emissions from all facilities provided in Supplementary Material, Annex 2).

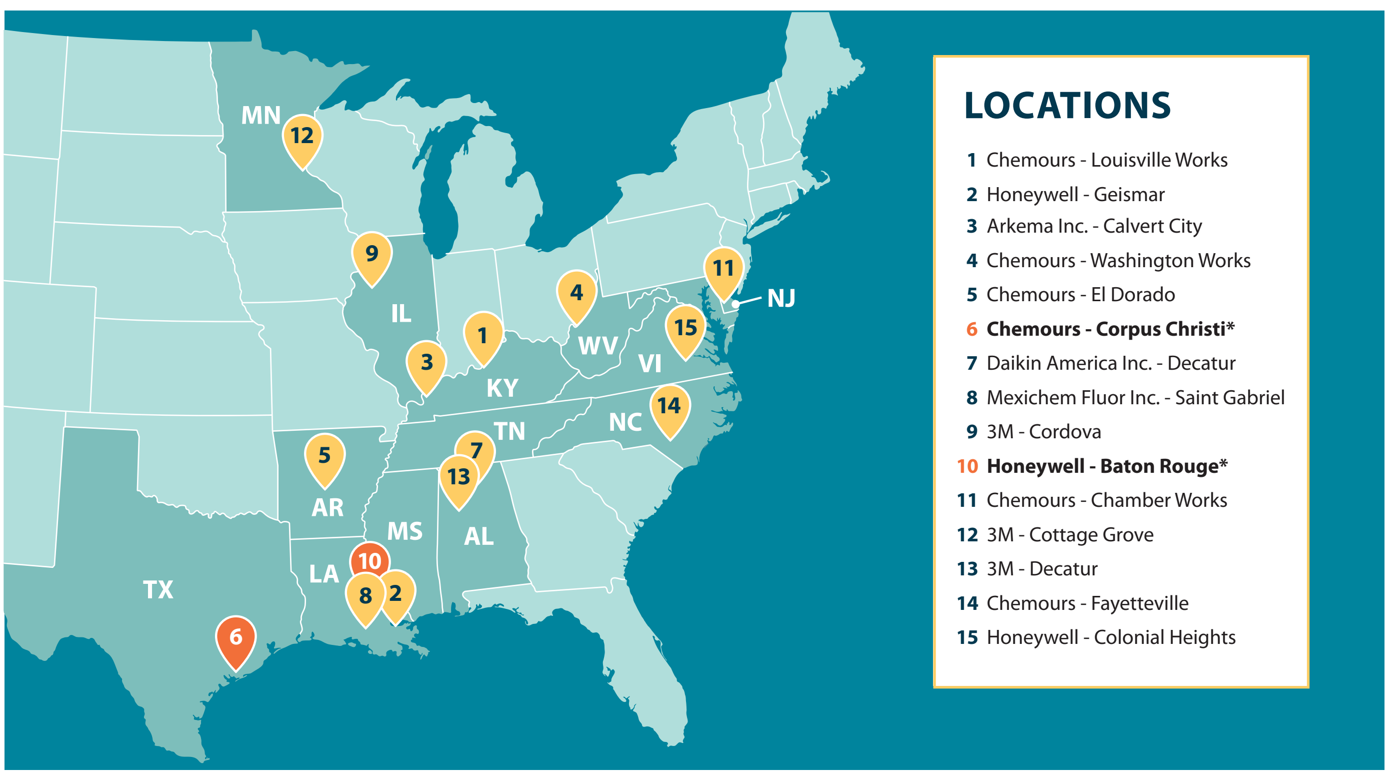
Figure 5 shows the locations of the top 15 chemical sector production facilities in the United States by total reported emissions of F-gases.[66] Overall, F-gas emissions reported by these facilities declined between 2018-2021, with the exception of CFCs. Total reported CFC emissions from the U.S. production facilities in Figure 5 increased by 16% from 2018 to 2021.

Publicly available information on the history and production activities of the two facilities in EIA's detection case study is summarized in the below profiles and F-gas emissions reported by the two facilities in recent years are provided in Tables 1 and 2.

Honeywell International, Baton Rouge, Louisiana

The plant began operation in 1945 as General Chemical, and then was operated by Allied Chemical until 1999, when AlliedSignal bought Honeywell International and assumed that name.[67] According to air permits and other available information, the facility produces HFC-143a, chlorotrifluoroethylene

Figure 5: Map of U.S. Top F-Gas Emitting Production Facilities[62]



Depicts top 15 chemical sector facilities by reported total emissions (Tonnes CO_2e) of F-Gases (See Supplementary Materials, Table 1).
*Included in EIA case study detection results.

Exterior of Honeywell facility, Baton Rouge, Louisiana.

(CTFE), HFO-1233zd and HFO-1234ze and conducts packaging and blending operations for a range of HFC-HFO blends. HFO-1234ze production began in 2015.[68] The facility also has the capability to produce CFCs-113 and -114.[69] The facility received permit approval to increase the production rate of both HFO-1234ze and HFO-1233zd in 2018[70] and approval for further increased production capacity of HFO-1234ze in 2019.[71] Honeywell reported that it had doubled production of HFO-1234ze in December 2022.[72] In 2017 Honeywell applied for a permit renewal to increase the production rate of CTFE including "increases in raw material feed rates."[73] CFC-113 is known to be used in production of CTFE.

Reported releases of several CFCs and HCFCs from the facility followed a rising trend beginning in 2015. On-site releases of CFC-113, CFC-114, and HCFC-123 increased after 2015.[74] CFC-113 releases from the facility increased by 52% in 2021 from 2014 levels, CFC-114 releases increased by 36%, and HCFC-123 increased by 35% over the same period (See Table 1).

Chemicals Produced:

- HFO-1234ze[75]
- HFO-1233zd
- HFC-143a
- CTFE (CFC-1113, or G-1113)
- Capability to produce CFC-113, CFC-114[76]

Table 1: Emissions Reported by Honeywell, Baton Rouge 2018-2021 (Metric Tons CO_2e)[77]

Reported Emissions	GWP (AR6)	2018	2019	2020	2021
CFC-113	6,520	672,801	980,009	1,452,108	837,063
HCFC-123a	396	14,720	17,591	17,494	17,686
CFC-114	9,430	288,979	378,167	314,053	311,987
HCFC-22	1,960	145,802	0	0	0
HCFC-123	90	829	1,249	1,227	1,067
CFC-13	16,200	89,699	0	0	0
CFC-12	11,200	34,469	0	0	0
HCFC-142b	2,300	2,185	0	0	0
HFC-245fa	962	0	0	0	7,426
HFC-143a	5,810	152,764	0	0	0

Table does not reflect partially available reporting data for the year 2022, which is available for HFCs reported under GHGRP but not for CFCs and HCFCs reported under TRI at the time of publication.

Exterior of Chemours facility, Corpus Christi/Ingleside, Texas.

Chemours, Corpus Christi/ Ingleside, Texas

The facility was built in 1991 to produce HFC-134a, and also produces HFC-152a, and HFO-1234yf. It began producing HFO-1234yf at the end of 2018.[78] **Reported emissions of several other CFCs and HCFCs** were relatively stable from 2018 through 2020, but **increased in 2021**, the most recent reporting year available (See Table 2).[79] The rise in reported emis-sions in 2021 constituted a 31% rise in CFC-113 and CFC-114 emissions compared with 2017 levels, and a 76% rise in HCFC-124 emissions. CFC-113 and CFC-114 are both associated with production of HFC-134a. In a 2020 air permit application, Chemours estimated site wide emissions of 0.059 lbs/hr for HFO-1234yf among several other gases, including CFCs -113 and -114.[80]

Chemicals Produced:

- HFC-134a
- HFC-152a
- HFO-1234yf[81]

Table 2: Emissions Reported by Chemours, Corpus Christi 2018-2021 ($MTCO_2e$)

Reported Emissions	GWP (AR6)	2018	2019	2020	2021
HFC-23	14,600	73,142	114,171	98,332	15,619
CFC-113	6,520	27,721	23,206	23,152	42,175
HCFC-124	597	1,028	1,134	964	5,138
CFC-115	9,600	34,734	1,800	1,668	17,662
CFC-114	9,430	9,518	9,171	9,193	14,926
HCFC-253fb[82]	58	0	60	60	60
HFC-134	1,260	1,635	1,445	0	1,796
HFC-152a	164	52	47	47	45
HFC-143a	5,810	1,850	1,662	1,655	1,587
HFC-134a	1,530	29,881	32,241	31,854	28,010
HFC-245cb	4,550	0	2,223	2,256	3,303

Table does not reflect partially available reporting data for the year 2022, which is available for HFCs reported under GHGRP but not for CFCs and HCFCs reported under TRI at the time of publication.

Detection Results

EIA analysis showed positive detection of CFCs, HFCs, and HFOs in samples taken near the Honeywell facility in Baton Rouge, Louisiana, and HFO-1234yf at the Chemours facility in Corpus Christi, Texas. Table 3 summarizes the peak concentrations detected for each substance and the calculated lowest detection limit (LDL), indicating that the concentrations detected were well above the lower limits of sensitivity of the Gasmet device under field conditions. This provides a high level of certainty with regard to positive identification of the substances based on guidelines from Gasmet and consultation with experts.

Several of the CFCs and HFCs detected at Honeywell's facility have not been reported in recent years under mandatory reporting programs. Most notably in 2022, HFC-125 and -143a were not reported for the period of EIA's detection. Data is not yet available to confirm reporting for 2023, and emissions reporting data for CFCs and HCFCs is incomplete for 2022. EIA did not attempt to quantify the volume of emissions for gases detected in this report but the fact that the gases were detectable at ppm levels at distances at least several hundred feet from the source of emissions indicates that the actual volumes are likely to be substantial.

Table 3: Summary Results for Gases Detected by EIA Field Sampling

Gas Detected	Peak Concentration (ppm)	Lowest Detection Limit (LDL) (ppm)[83]	Location / Facility	Emissions Reported under GHGRP and TRI (2018-2022)*
CFCs				
CFC-113	0.24	0.1547	Honeywell, Baton Rouge	Yes, reported emissions show recent increase
CFC-114	0.16	0.0427	Honeywell, Baton Rouge	Yes, reported emissions show recent increase
CFC-13	0.36	0.0308	Honeywell, Baton Rouge	2018 only, not reported for 2019-2021
HFCs				
HFC-32	3.91	0.0447	Honeywell, Baton Rouge	No
HFC-125	2.72	0.0569	Honeywell, Baton Rouge	No, and not reported for 2022, the year of detection
HFC-134a	2.37	0.0758	Honeywell, Baton Rouge	No
HFC-143a	2.57	0.0316	Honeywell, Baton Rouge	Yes until 2018, not reported for 2019-2021 or 2022, the year of detection
HFC-245fa	0.82	0.0534	Honeywell, Baton Rouge	Yes, 2021-2022 only
HFOs				
HFO-1234yf	1.01	0.0347	Chemours, Corpus Christi	N/A, reporting not required
HFO-1234ze	2.03	0.0175	Honeywell, Baton Rouge	N/A, reporting not required
HFO-1233zd	1.46	0.0614	Honeywell, Baton Rouge	N/A, reporting not required

***Note:** Publicly available data on HFC emissions reported under Subparts L and O of the EPA Greenhouse Gas Reporting Program (GHGRP) up to 2022, available here. CFC and HCFCs are reported to EPA Toxics Release Inventory (TRI) up to 2021, available here. TRI facility profile for Honeywell, Baton Rouge available here.

CFCs Detected

Several CFCs, ODS with high GWPs, were detected in air samples from detection sites outside the Honeywell, Baton Rouge facility. CFC-113 (6,520 GWP), CFC-114 (9,430 GWP), and CFC-13 (16,200 GWP) were detected reaching concentrations as high as 0.24 ppm, 0.16 ppm, and 0.36 ppm respectively (see Figure 6(a), Figure 6(e), and time series Figure 7(b)).

Several of the HFCs detected have not been reported by Honeywell under mandatory federal emissions reporting for recent years. Most notably, HFC-125 and HFC-143a were not reported by Honeywell in 2022, the same period when EIA detection of those substances took place.

HFCs Detected

Analysis of air samples collected from outside the Honeywell, Baton Rouge facility revealed the presence of numerous HFCs including; HFC-32 (771 GWP), HFC-125 (3,740 GWP), HFC-134a (1,530 GWP), HFC-143a (5,810 GWP), and HFC-245fa (962 GWP).[84] In air samples HFC-32 and HFC-134a were recorded at concentrations as high as 3.91 ppm and 2.37 ppm, respectively (Figure 6(b)). HFC-125 concentrations were observed as high as 2.72 ppm (Figure 6(b)). Time series data (Figure 7(a)) indicates that HFC-134a and HFC-125 were typically present during the same intervals as HFC-32. HFC-245fa was also observed in air samples, with a peak concentration of 0.82 ppm (Figure 6(f)).

Several of the HFCs detected have not been reported by Honeywell under mandatory federal emissions reporting for recent years. Most notably, HFC-125 and HFC-143a were not reported by Honeywell in 2022, the same period when EIA detection of those substances took place.

HFOs Detected

HFO-1234ze was observed at Honeywell, Baton Rouge in two separate air sample sessions in concentrations up to 2.03 ppm (Figure 6(c)). We also found HFO-1233zd in concentrations up to 1.46 ppm near the fenceline of the same facility (Figure 6(h)). As noted in the facility profile above, both substances are produced at this facility. Neither substance is covered under existing applicable reporting programs of toxic substance releases or greenhouse gases emissions, as (further described in Supplementary Material, Annex 3).

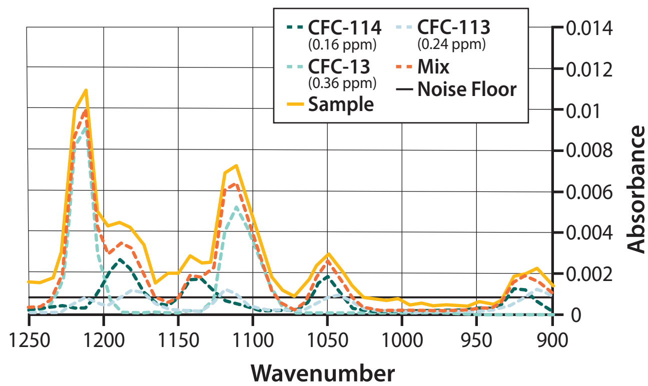
Similar concentrations of HFO-1234yf, up to 1.01 ppm, were observed during several air sample sessions outside of the Chemours, Corpus Christi facility, as shown in Figure 6(d) and time series data (Figure 7(c)). As is the case for the HFOs detected at the other facility, this substance is produced at the facility and is not covered under currently required federal emissions reporting programs.

Gasmet equipment used for data collection.

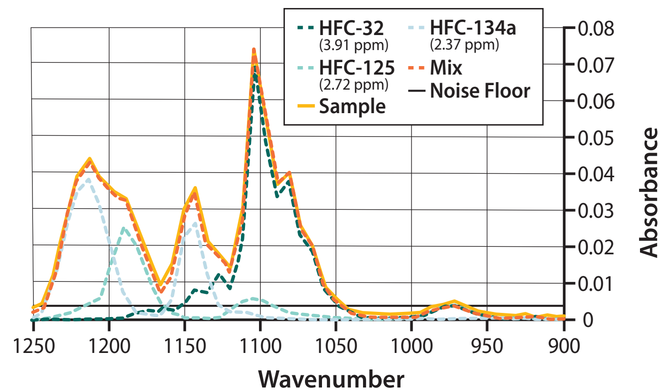
Figure 6: Infrared Spectroscopy Matches for Peak Samples

Note on reading graphs: Infrared spectroscopy measures how a gas absorbs infrared radiation, showing the unique "fingerprint" visual representation of a gas. The individual gases, or "reference" lines, add up to the mix line, which can then be matched to the sample line, or what was detected in the field. Noise was determined by measuring the height of the oscillation at the section of wavelength where the sample is most flat, then doubling this measurement to arrive at the noise floor.

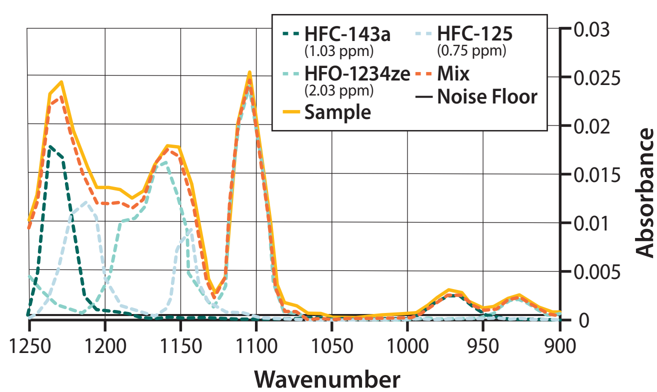
Figure 6 represents a selection of peak samples of each type of gas detected at the respective facilities. The figure captions below list the detection location, detected gases, and their corresponding wavenumber peaks.



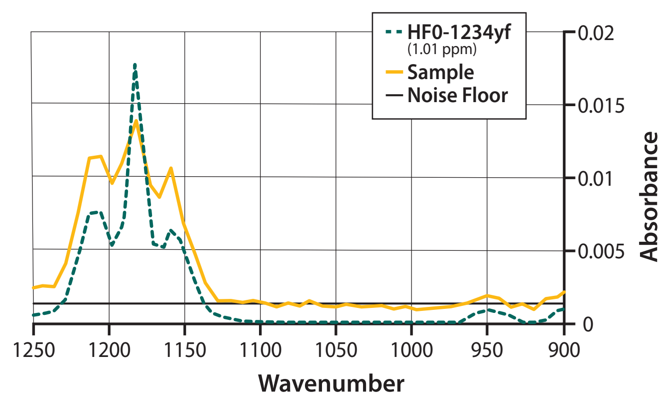
a. CFCs Detected at Honeywell, Baton Rouge
CFC-13 Peaks at 1212, 1111, 1049
CFC-113 at 1181, 1119, 910
CFC-114 at 1188, 1142, 1049, 926



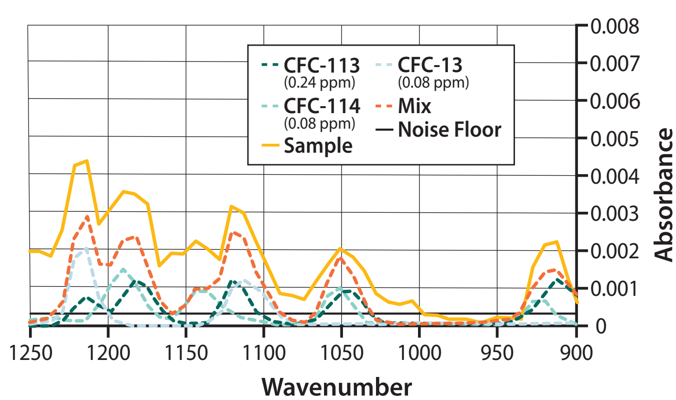
b. HFCs Detected at Honeywell, Baton Rouge
HFC-32 Peaks at 1103
HFC-134a at 1188, 1103
HFC-125 at 1212, 1142



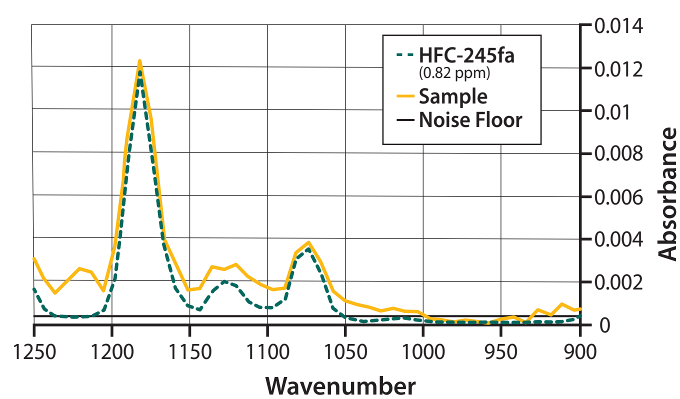
c. HFO-1234ze Detected at Honeywell, Baton Rouge
HFC-143a Peaks at 1242, 972
HFC-125 at 1212, 1150
HFO-1234ze at 1158, 1103, 926



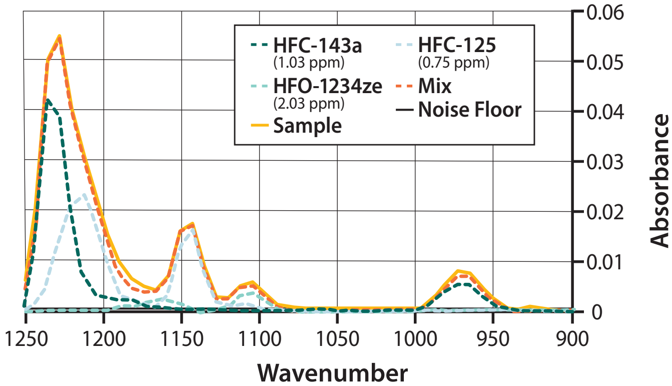
d. HFO-1234yf Detected at Honeywell, Baton Rouge
Peaks at 1212, 1181, 1158



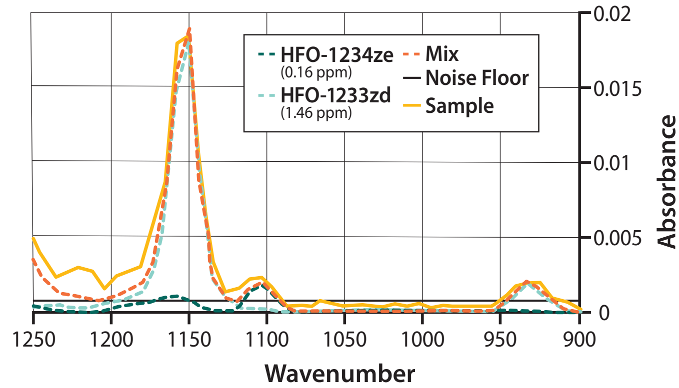
e. CFCs Detected at Honeywell, Baton Rouge
CFC-113 Peaks at 1212, 1181, 1119, 1042, 910
CFC-13 at 1212, 1111
CFC-114 at 1188, 1142, 1049, 926



f. HFC-245fa Detected at Honeywell, Baton Rouge
Peaks at 1181, 1073



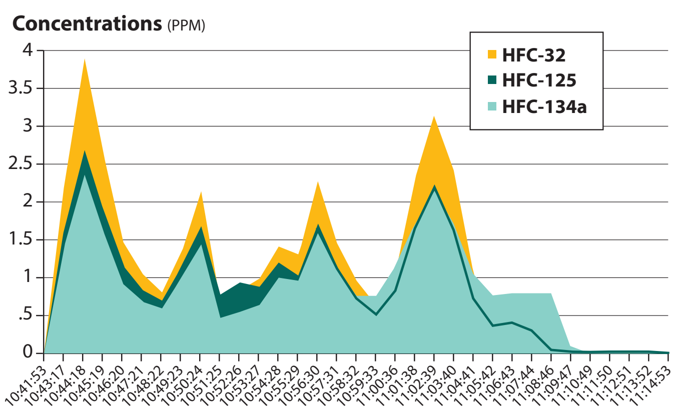
g. HFC-143a Detected at Honeywell, Baton Rouge
HFC-143a Peaks at 1242
HFC-125 at 1212, 1142
HFO-1234ze at 1165, 1103



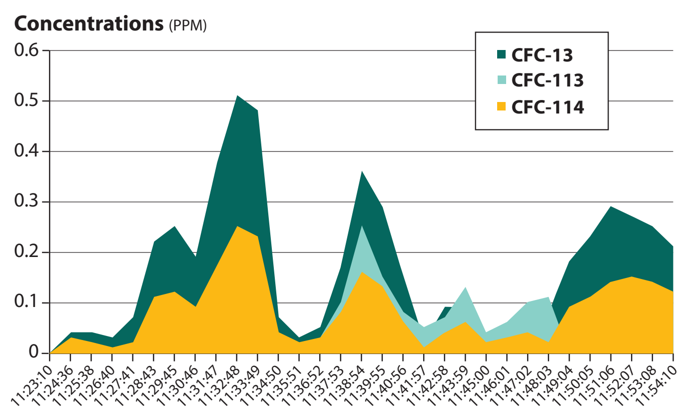
h. HFO-1233zd Detected at Honeywell, Baton Rouge
HFO-1234ze Peaks at 1158, 1103
HFO-1233zd at 1150, 934

Figure 7: Time Series and Concentrations Detected

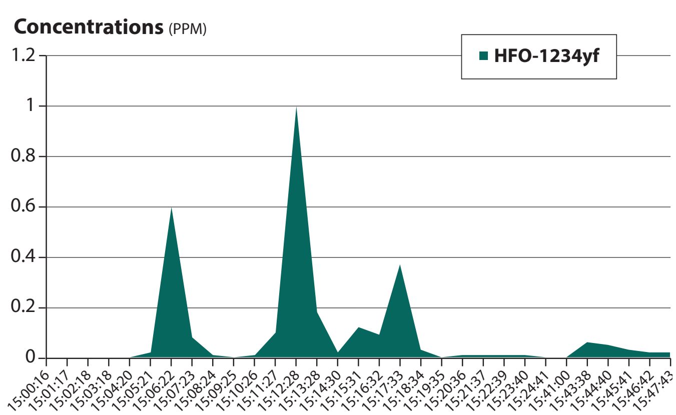
Note on reading graphs: This figure represents three 30-45-minute time sessions showing the fluctuations of concentrations of each class of F-gases detected at the two facilities in ppm.



a. Time Series of HFCs at Honeywell, Baton Rouge



b. Time Series of CFCs at Honeywell, Baton Rouge



c. Time Series of HFOs at Chemours, Corpus Christi

New Approaches for Rapid and Targeted Emissions Monitoring

Current emissions monitoring of F-gases and other controlled substances under the Montreal Protocol currently relies primarily on analysis of atmospheric measurements taken at static sampling stations and analyzed on global, hemispheric, or regional levels. While these atmospheric studies provide vital insights into emissions trends, they have inherent limitations both in terms of the time lags between data collection, analysis and publication, as well as their limited geographic specificity. This presents challenges for pinpointing, verifying, and quantifying any specific or concentrated sources of emissions, such as those from production facilities. Significant gaps also remain in the regional coverage and locations of measurement stations globally, with a lack of a coherent strategy to achieve full coverage.

For example, the seminal atmospheric study that alerted the international community to unexplained rising emissions of CFC-11 was published in 2018, but the emissions are believed to have begun in 2012 or earlier. The illegal production, use, and emissions of CFC-11 persisted for at least six years before enforcement action was taken.[85] More rapid forms of detection and monitoring could have prevented billions of tonnes of CO_2e from entering the atmosphere. Furthermore, while the majority of the emissions were regionally pinpointed to Eastern China,[86] and widespread illegal use of CFC-11 in China's foam sector was confirmed by EIA investigations,[87] the comprehensive identification of the specific locations and facilities responsible for the illegal production of CFC-11 remains uncertain.

The illegal production, use, and emissions of CFC-11 persisted for at least six years before enforcement action was taken. More rapid forms of detection and monitoring could have prevented billions of tonnes of CO_2e from entering the atmosphere.

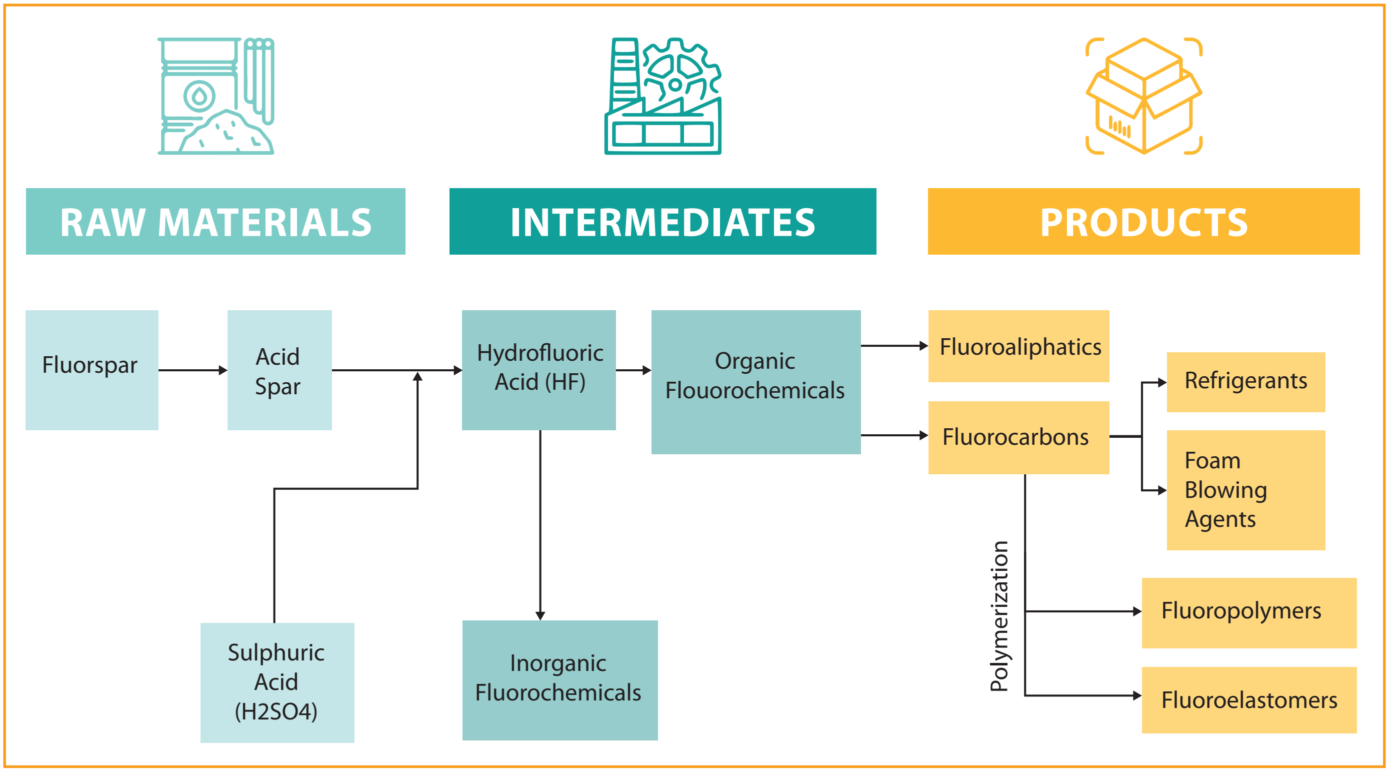
Promising scientific approaches to implement rapid and targeted emissions monitoring exist, and should be explored or further scaled by policymakers, scientists, and industry. The portable in situ air sampling measurements and analysis demonstrated in this report's case study provides one such approach. Other promising approaches have been deployed utilizing longwave-infrared (LWIR) spectral imaging for either ground-based or aerial monitoring to successfully detect, identify, and pinpoint F-gas emissions with high sensitivity and specificity.[88] Controlled substance producing companies and countries must allocate resources, for example as part of their MRV&E systems to further pilot and identify approaches for high altitude and satellite-based LWIR monitoring.

Chemical Pathways and Emissions

Fluorochemical production often involves multiple steps and complex processes in the chemical pathways to produce an end-product. Raw materials from minerals are processed to produce precursors and intermediates, which are used to finally make the end-product. The chemical production pathways can involve several steps, each with the potential to

Plume of HCFC-22 detected by M. Ghandehari et al (2017) using a ground based, long-wave infrared (LWIR) hyperspectral imaging (HSI) sensor.

Figure 8: Illustration of Fluorochemical Production Chain



Polymerization of fluorocarbons is an example of a production process whereby CFCs, HCFCs, and HFCs are used as feedstock substances transformed in producing longer more complex molecules such as fluoropolymers or fluoroelastomers. The largest volume feedstock is HCFC-22 used to produce fluoropolymers (primarily PTFE, or Teflon) and refrigerants.

produce various emissions and by-products along the way (see Figure 8).

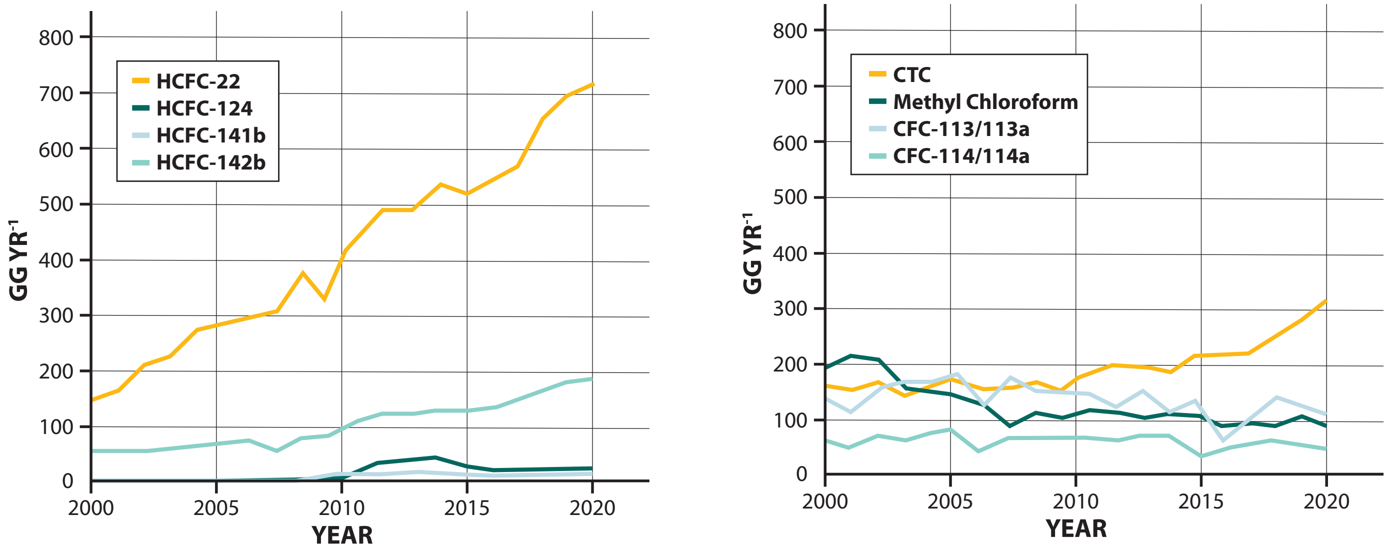
Production of ozone depleting fluorocarbons has increased substantially over the past two decades, despite their phase-out under the Montreal Protocol.[89] This is due to growing production for feedstock uses, which are exempted under the treaty's control measures.[90] ODS feedstock use increased by 75% between 2009 and 2019 and production related to feedstock usage increased by more than a factor of five from 2000 to 2019.[91]

The most widely used feedstock is HCFC-22. Global feedstock production of HCFC-22 has increased dramatically to meet growing demand for production of fluoropolymers and HFOs. More HCFC-22 was produced for feedstock in 2019 than any other fluorocarbon in history. In 2020, 97% of the 713,536 tonnes that were produced as feedstock were used to produce tetrafluoroethylene (TFE) and hexafluoropropene (HFP), used in fluoropolymer production, mainly PTFE (i.e. Teflon).[92] CTC (or CCl4)

Production of ozone depleting fluorocarbons has increased substantially over the past two decades, despite their phase-out under the Montreal Protocol.

is the second most widely produced feedstock substance with more than 300,000 tonnes produced annually in 2019.[93] CTC production has increased by a factor of two in the past decade driven by demand to manufacture HFOs.[94] As of 2015, 65% of global HCFC-22 was produced in China.[95] A number of new HCFC feedstock production lines were established in China between 2019-2022, during the same period of unexpected rising emissions of substances related to production, including HFC-23.[96] Global fluorocarbon production is likely to continue to increase despite the phase-out and phase-down of ODS and HFCs under the Montreal Protocol unless feedstock uses are controlled and reduced (see Figure 9).[97]

Figure 9: Rising Global Feedstock Production (WMO, 2022)[98]



Although production of HCFC-22 and other ODS feedstock has declined in the United States, having shifted overseas, the U.S. continues to produce a significant quantity of HFCs for domestic use and export, and has rapidly expanded production capacity for HFOs as HFC replacements.[99] Both HFC and HFO production use ozone depleting and climate warming chemicals as feedstocks, which are emitted along with potent by-products. Feedstock uses in production are also exempt under Montreal Protocol limits on controlled substances. Both facilities in EIA's case study are sites of continued HFC production and new production of HFOs, which has increased rapidly in recent years along with the facilities' reported emissions of certain associated feedstock or by-product substances, particularly several CFCs. (See Facility Profiles and Table 3).[100, 101]

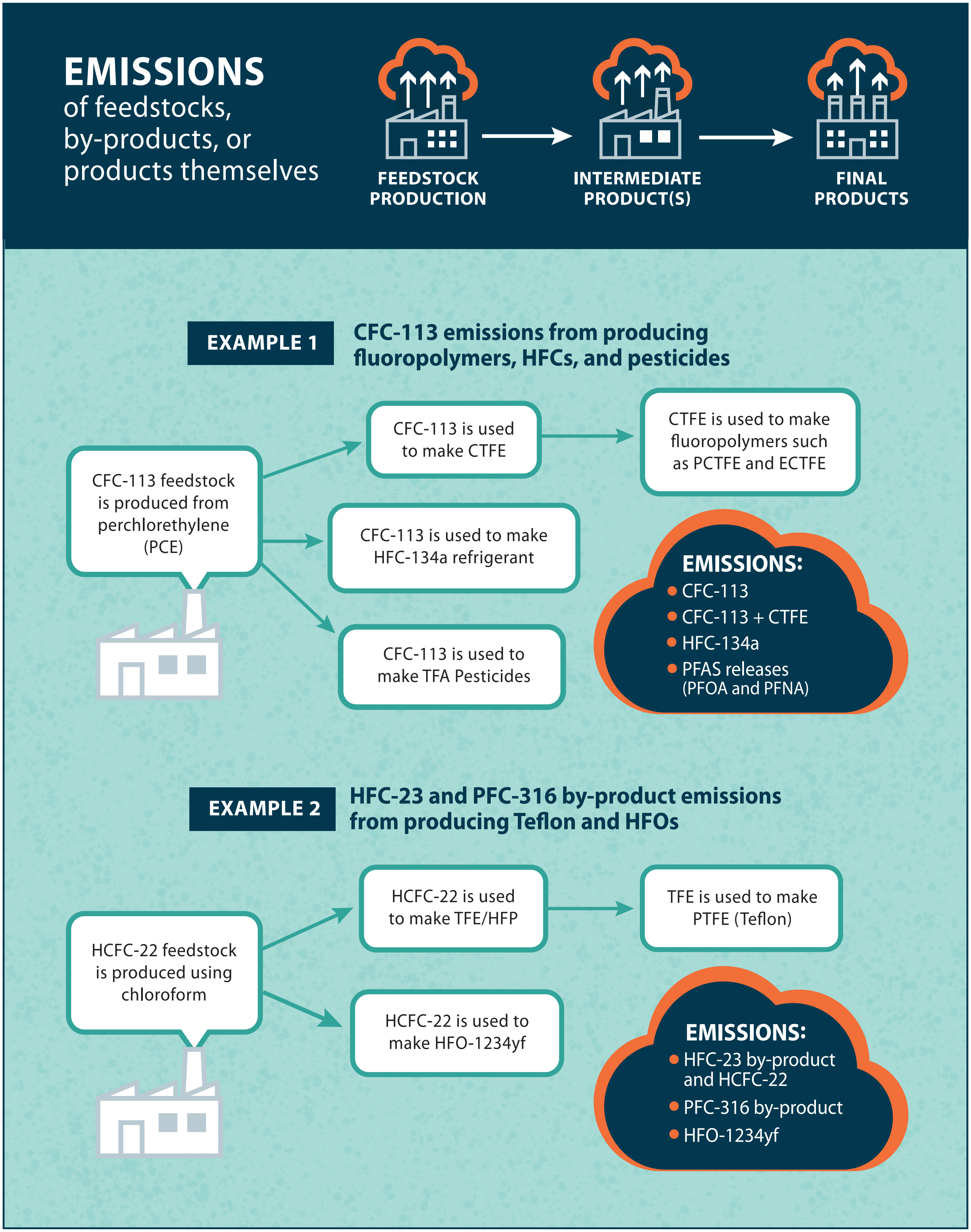
Emerging Information on Chemical Pathways with Significant Emissions

New information is emerging regarding production pathways that may result in significant emissions. An initial assessment by international experts to the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol has identified 24 chemical pathways for production of controlled substances likely to result in substantial emissions.[102] This analysis does not include emissions of substances outside of the scope of Montreal Protocol controlled substances, including PFCs and HFOs. More information on emissions from chemical pathways and by-products such as HFC-23 is expected to be published in a subsequent report to the 36th Meeting of Parties (MOP) of the Montreal Protocol. Figure 10 provides examples of chemical production pathways with potential significant emissions. Several of the substances detected by EIA outside of U.S. facilities are included in the TEAP's assessment of chemical pathways likely to produce significant emissions.

Both HFC and HFO production use ozone depleting and climate warming chemicals as feedstocks which are emitted along with potent by-products. Feedstock uses in production are also exempt under Montreal Protocol limits on controlled substances.

The sources of emissions from fluorochemical production processes include fugitive emissions which unintentionally leak from the production process equipment and/or packaging of products on site, and process related emissions which are emitted from concentrated stacks or vents. In most cases, the production of an end product involves multiple stages of production of feedstock and/or chemical intermediate substances. In some cases, these steps may be vertically integrated at a single facility, or in other cases they may take place at multiple facilities and involve additional emissions during packaging and transport.

Figure 10: Examples of Fluorochemical Production Pathways with Significant Emission[103]



Box 2: Types of Substances Emitted During Production

The substances emitted from production facilities can include feedstocks, intermediates, process agents, catalysts, unwanted **by-products**, and **co-products or products** themselves. **A feedstock use** is a substance that is transformed from one chemical into another during the production process. Feedstock uses are exempted under Montreal Protocol limits on production and consumption, but quantities produced and used as feedstock are required to be reported.[104] The decision by countries to exempt feedstock use was premised on emissions from feedstock use being 'insignificant',[105] which appears increasingly in question.

In cases where a substance is used as a feedstock in situ or in a single plant complex, it is considered an "intermediate." Such uses are typically not reported as production of controlled substances for feedstock use under the Montreal Protocol.[106] Therefore, the production and emissions from intermediates may be undercounted in estimates based on country reporting. In a process agent use, the chemical is used but not transformed during the process, such as in a solvent used during production.

A catalyst is a substance used to modify the production reaction such as by speeding it up or changing the temperature at which a reaction takes place. While catalysts are not a significant source of greenhouse gases or ODS, certain catalysts used in fluorocarbon production are highly toxic, including several nickel, chromium, and antimony compounds.[107]

Finally, fluorochemical production processes produce unwanted **by-products or co-products.** By-production is often a result of over or under reaction in making the intended product and can be minimized through optimization of the production process.[108] Notable harmful high-GWP by-products of fluorochemical production include HFC-23, and PFC-318. **CFCs**-113, -114, and -115 **can also be produced in making HFC-125, for example.** As HFC-23 is a high-volume by-product of HCFC-22 production, countries agreed to make destruction of HFC-23 by-product a mandatory control measure under the Kigali Amendment.

Estimating Production Emissions

There is a high level of uncertainty about applying accurate emissions factors for production of feedstocks and other fluorochemicals. According to experts from the TEAP, emission rates are likely to vary over time, from process to process, and can be impacted by a range of factors including the chemical pathway itself, feedstock impurities, feedstock feed ratios, operating conditions, catalyst condition and composition, use of continuous, discontinuous, and emergency release points, and notably, the operation of mitigation and destruction steps.[109]

Recent emissions factors applied to fluorochemical production have typically ranged from 2-4% (4.3% for CTC).[110] The TEAP Medical and Technical Options Committee (MCTOC) was tasked in its most recent report with examining potential emissions factors related to production and feedstock use, which provided "low," "most-likely," and "high" scenarios for "modern-day, regulated manufacturing facilities."[111] The emission factors for feedstock production, distribution, and use, assuming no use of disposable cylinders, are presented as between 1.3-5.9% in a most-likely scenario, and up to 12% in a high scenario. By comparison, significantly higher emissions factors were determined to be applicable for illegal production plants that were speculated to have supplied the unexplained CFC-11 emissions between 2012-2018, which were estimated to have the potential to exceed upward of 15% of total production volume.

Under a "most-likely" scenario applying a total average emissions factor of 3.6%, and using reported production from 2020, total emissions from ODS feedstocks are estimated to be approximately 126.6 million tonnes CO_2e annually (see Table 4). Using the same emissions factor for HFC production, the MCTOC estimated emissions from HFC production at 42.8 million tonnes CO_2e annually in 2020, based on incomplete reporting.[112] As the MCTOC estimated the incomplete reporting of HFC production data in 2020 to account for about 80% of total production, total emissions most likely exceed 50 million tonnes CO_2e. **This brings the total combined estimated emissions from ODS feedstock and HFC production and feedstock to over 170 million tonnes CO_2e in 2020.** This figure does not include emissions of by-products.

Applying a "high" scenario emissions factor to the same analysis of 12%,[113] the estimated emissions balloon to 422 million tonnes CO_2e annually for ODS feedstock and 155 million tonnes for HFCs, bringing the new total to 576 million tonnes CO_2e.[114] While these high scenario estimates are unlikely given comparison with estimated top-down atmospheric estimates, it **illustrates the significant uncertainty, and lack of transparency and ground truthing of realistic emissions factors for production facilities globally**. In a scenario where some portion of global fluorocarbon production is in line with feasible higher emissions factors upward of 12%, this would significantly impact total production related emissions.

Table 4: Estimated Annual Emissions of ODS Feedstock Production and Use[115]

Substance	Quantity (metric tonnes)	GWP	Total Emissions Factor	Emissions (Tonnes CO_2e)	Emissions (Metric tons)	Total Emissions Factor	Emissions (Tonnes CO_2e)	Emissions (Metric tons)
			Most Likely Emissions Scenario (Production: 2.5% Distribution: 0.5% Feedstock Use: 0.6%)			**High Emissions Scenario** (Production: 7% Distribution: 2% Feedstock Use: 3%)		
HCFC-22	713,536	1,960	3.6%	50,347,100	25,687	12.0%	167,823,667	85,624
CTC	288,935	2,150	3.6%	22,363,569	10,402	12.0%	74,545,230	34,672
HCFC-142b	166,966	2,300	3.6%	13,824,785	6,011	12.0%	46,082,616	20,036
CFC-113	138,443	6,520	3.6%	32,495,341	4,984	12.0%	108,317,803	16,613
CFC-114	20,000	9,430	3.6%	6,789,600	720	12.0%	22,632,000	2,400
HCFC-141b	10,000	860	3.6%	309,600	360	12.0%	1,032,000	1,200
HCFC-133	1,000	388	3.6%	13,968	36	12.0%	46,560	120
HCFC-124	20,000	597	3.6%	429,840	720	12.0%	1,432,800	2,400
Total				**126,573,803**	**48,920**		**421,912,676**	**163,066**

Mitigating Production Emissions

The best practices and technologies currently available to mitigate production related emissions include:

- Optimization of equipment, operation, and maintenance; including the instrumentation and monitoring of process emissions;
- Training and instruction for plant operators; and mandatory periodic mass balancing;
- Installation and the use of technologies for destruction, or for separation and chemical transformation to treat unwanted co-products or by-products and abate their emissions.

Experts have pointed to limited transparency and reporting on specific chemical pathways and production quantities and locations of facilities as a challenge to accurately estimating production emissions impacts.[116] Furthermore, operation of installed mitigation technologies such as destruction may be economically disincentivized due to their operational costs.

Regulatory controls are necessary to provide an economic framework that requires the abatement of emissions, ensuring that operators actually employ available mitigation measures and best practices. Controlling emissions may also be in the best economic interest of producers to avoid waste of valuable resources. Such controls should include transparent reporting, and/or third-party monitoring, to verify the continued use of any installed destruction technologies or other measures to minimize emissions.

Conclusion and Recommendations

The significant emissions from the fluorochemical production sector are becoming more apparent and visible in atmospheric measurements, despite a lack of transparency and bottom-up data and information. **EIA's fenceline detection of F-gases that have not been previously reported indicates uncertainty around emissions from production facilities.** This further underscores the urgency and feasibility of pinpointing and eliminating these avoidable production emissions. The United States remains a major global producer and consumer of fluorochemicals and has a responsibility to help lead a global coalition toward investing in the technology and policy solutions to end industrial emissions of F-gases, and to implement solutions domestically.

To strengthen monitoring and verified reduction of these emissions, EIA recommends:

- **Reducing information asymmetry** on chemical production pathways, production locations, quantities, including through greater transparency and reporting of data from all producing countries and companies;
- **Scaling up investment** in atmospheric monitoring, particularly new technologies and approaches for rapid and targeted emissions detection and other localized monitoring of F-gases, particularly in regions with known concentrated production of fluorocarbons and fluoropolymers;
- **Reexamining the exemption of feedstock uses** under the Montreal Protocol, given emerging information about the significance of emissions and considering additional compliance mechanisms to eliminate unnecessary feedstock production and use;
- **Enhancing and modernizing the MRV&E framework** under the Montreal Protocol more comprehensively to prevent illegal production and use and resulting emissions;
- **Strengthening and expanding** existing national and sub-national emissions **monitoring and reporting** mandates and requiring mitigation of all by-product emissions of F-gases. This should include requiring reporting of HFOs and other PFAS emissions;
- **Adopting tighter controls on production emissions**, such as requiring process optimization, avoidance of high-emitting pathways for production of specific chemicals, and installation and use of destruction and other in-line mitigation systems in existing facilities, with mandatory third party verification of implementation and use of such systems;
- **Seeking to eliminate all non-essential uses of fluorinated substances** classified in the broader PFAS definition and transitioning to non-fluorinated (PFAS-free) and ultra-low GWP alternatives for each sector of significant use and emissions, including refrigerants.

References

1 For examples of infrared spectroscopy applied to detection of greenhouse gases, see Zhang, Eric J., et al. “Field deployment of a portable optical spectrometer for methane fugitive emissions monitoring on oil and gas well pads.” Sensors 19.12 (2019): 2707, available here.; Peng, Wei, et al. “Applications of near infrared spectroscopy and hyperspectral imaging techniques in anaerobic digestion of bio-wastes: A review.” Renewable and Sustainable Energy Reviews 165 (2022): 112608, available here; Wang, Jingfan, et al. “Machine vision for natural gas methane emissions detection using an infrared camera.” Applied Energy 257 (2020): 113998, available here.; and many others.

2 Recent application of infrared spectroscopy to identifying fluorocarbons includes: Tratt, David M., et al. “Identification and source attribution of halocarbon emitters with longwave-infrared spectral imaging.” Remote Sensing of Environment 258 (2021): 112398., available here; See also; Ghandehari, Masoud, et al. “Mapping refrigerant gases in the New York City skyline.” Scientific reports 7.1 (2017): 2735, available here.

3 Environmental Investigation Agency (EIA), Blowing it: Illegal Production and Use of Banned CFC-11 in China’s Foam Blowing Industry, (2018), available here.

4 Emissions estimates and sources are referenced in the corresponding papers in Figure 1, the World Meteorological Organization (WMO), “Scientific Assessment of Ozone Depletion: 2022”, GAW Report No. 278, 56 pp.; WMO: Geneva, 2022. (WMO, 2022), available here and the Technology and Economic Assessment Panel, Volume 1: Progress Report (UNEP, 2021), available here, See Table 5.1 for feedstock uses.

5 United Nations Environment Program (UNEP), State of the Climate (2021), available here.

6 WMO, 2022, p. 121.

7 Lickley, M. et al., “Joint inference of CFC lifetimes and banks suggests previously unidentified emissions”, Nature communications 12.1 (2021): 2920, available here.

8 Ibid.

9 Sherry, D. et al., “Current sources of carbon tetrachloride (CCl4) in our atmosphere”, Environmental Research Letters, 13 024004, 2018, available here.

10 Lickley, M. et al., “Joint inference of CFC lifetimes and banks suggests previously unidentified emissions”, Nature communications 12.1 (2021): 2920, available here.

11 WMO, 2022, p. 399.

12 Ibid., p. 100.

13 Western, L. M., et al., “Global increase of ozone-depleting chlorofluorocarbons from 2010 to 2020”, Nature Geoscience 16.4 (2023): 309-313, available here.

14 Ibid.

15 Ibid.

16 Ibid.

17 Vollmer, M. et al., “Unexpected nascent atmospheric emissions of three ozone-depleting hydrochlorofluorocarbons”, Proceedings of the National Academy of Sciences, 118(5), (2021), available here.

18 Ibid.

19 Western, L. M., et al., “Global increase of ozone-depleting chlorofluorocarbons from 2010 to 2020”, Nature Geoscience 16.4 (2023): 309-313, available here.

20 Vollmer, M. et al., “Unexpected nascent atmospheric emissions of three ozone-depleting hydrochlorofluorocarbons”, Proceedings of the National Academy of Sciences, 118(5), (2021), available here.

21 Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Program, “Report of the Medical and Chemical Technical Options Committee”, (MCTOC, 2022) available here.

22 Taddonio, K. N., et al., “Trifluoroiodomethane as a Precursor to High Global Warming Potential Climate Pollutants: Could the Transformation of Climatically Benign CF3I into Potent Greenhouse Gases Significantly Increase Refrigerant-Related Greenhouse Gas Emissions?” Environmental Science & Technology (2023), available here.

23 Stanley, K. M., Say, D., Mühle, J., Harth, C. M., Krummel, P. B., Young, D., ... & Rigby, M., “Increase in global emissions of HFC-23 despite near-total expected reductions”, Nature communications, 11(1), 1-6, (2020), available here; See also: Solomon, S., Alcamo, J., & Ravishankara, A. R., “Unfinished business after five decades of ozone-layer science and policy”, Nature Communications, 11(1), 1-4, (2020), available here.

24 WMO, 2022

25 Ibid.: See Figures 2-9 and 2-10.

26 Park, H.,et al: A rise in HFC-23 emissions from eastern Asia since 2015, Atmos. Chem. Phys., 23, 9401–9411, 2023, available here.

27 Park, H. et al., “A rise in HFC-23 emissions from eastern Asia since 2015”, (2023), as cited in presentation by Stephen Montzka (2023), HFC-23 Side-event at OEWG-45, available here.

28 Western, L. M. et al., “Global increase of ozone-depleting chlorofluorocarbons from 2010 to 2020”, Nature Geoscience, 1-5, (2023), available here.

29 Vollmer, M. K., et al., “Atmospheric histories and emissions of chlorofluorocarbons CFC-13 (CClF3), ∑CFC-114 (C2Cl2F4), and CFC-115 (C2ClF5)”, Atmos. Chem. Phys., 18, 979–1002, (2018), available here.

30 Vollmer, M. K. et al., “Unexpected nascent atmospheric emissions of three ozone-depleting hydrochlorofluorocarbons”, Proceedings of the National Academy of Sciences, 118(5), e2010914118, (2021), available here.

31 Mühle, J. et al., “Global emissions of perfluorocyclobutane (PFC-318, c-C 4 F 8) resulting from the use of hydrochlorofluorocarbon-22 (HCFC-22) feedstock to produce polytetrafluoroethylene (PtFE) and related fluorochemicals”, Atmospheric Chemistry and Physics, 22(5), 3371-3378, (2022), available here.

32 WMO, 2022

33 The breakdown in the bottom-up emissions estimate is 13gg from chloromethane and perchloroethylene (PCE) plants as the most significant source, 2gg/yr estimated from feedstocks and possibly up to 10gg from legacy emissions and chlor-alkali plants. Sherry, D. et al., “Current sources of carbon tetrachloride (CCl4) in our atmosphere”, Environmental Research Letters, 13(2), 024004, (2018), available here.

34 The breakdown in the bottom-up emissions estimate is 13gg from chloromethane and perchloroethylene (PCE) plants as the most significant source, 2gg/yr estimated from feedstocks and possibly up to 10gg from legacy emissions and chlor-alkali plants. Sherry, D. et al., “Current sources of carbon tetrachloride (CCl4) in our atmosphere”, Environmental Research Letters, 13(2), 024004, (2018), available here.

35 United Nations Intergovernmental Panel on Climate Change, AR6 Synthesis Report (2023), available here.

36 Mordor Intelligence, Market Research Survey, Fluorochemical Market Size & Share Analysis (2023), available here.

37 United Nations Environment Program, Ozone Secretariat, Text of Kigali Amendment to the Montreal Protocol, (2016), available here.

38 OECD, Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, (2021), available here; See also European Chemical Agency (ECHA), Annex XV Report (2023), Registry of Restriction intentions, available here; See also Maine and California statues.

39 United Kingdom, Health and Safety Executive, Regulatory management option analysis (RMOA), (April 2023), available here.

40 Pickard, H. M. et al., “Ice core record of persistent short-chain fluorinated alkyl acids: Evidence of the impact from global environmental regulations”, Geophysical Research Letters 47.10 (2020): e2020GL087535, available here.

41 Cahill, T. M., “Increases in Trifluoroacetate Concentrations in Surface Waters over Two Decades”, Environmental Science & Technology 56.13 (2022):9428-9434, available here; See also: Zhai, Z. et al. “A 17-fold increase of trifluoroacetic acid in landscape waters of Beijing, China during the last decade”, Chemosphere 129 (2015):110-7, available here.

42 This is an illustrative figure and not a comprehensive representation of all applications and sectors of fluorochemical uses.

43 National Institutes of Health, PFAS family tree fact sheet, (2017), available here.

44 Mordor Intelligence, Market Research Survey, Fluorochemical Market Size & Share Analysis, (2023), available here.

45 Ibid.

46 Ibid.

47 Ibid.

48 EPA, Master List of PFAS Substances, available here; See also OECD, Comprehensive Global Database of PFAS, available here.

49 OECD, Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, (2021), available here; See also European Chemical Agency (ECHA) proposal (2023), Registry of Restriction intentions, available here; See also California Health and Safety Code, CHAPTER 12.5. Juvenile Products [108945 - 108947], (2021), available here; See also, Maine Department of Environmental Protection, Public Law C477, (2023), available here.

50 PFAS are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS. OECD, “Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance”, Series on Risk Management No. 61, (2021), available here.

51 European Chemicals Agency (ECHA), Registry of restriction intentions until outcome, (2023), available here.

52 California AB-652, Product safety: juvenile products: chemicals: perfluoroalkyl and polyfluoroalkyl substances, (October 2021), available here.

53 Maine Legislature, An Act To Stop Perfluoroalkyl and Polyfluoroalkyl Substances Pollution, (2021), available here.

54 European Chemical Agency (ECHA), Annex XV Report (2023), Registry of Restriction intentions, available here.
55 Mordor Intelligence, Market Research Survey, Fluorochemical Market Size & Share Analysis (2023), available here.
56 Article 7 data reported to Montreal Protocol, available here.
57 See U.S. Environmental Protection Agency, AIM Act Allowance Allocations, available here.
58 Article 7 Data Reporting on US HCFC Production, available here.
59 Louisiana Department of Environmental Quality, Final Permit Approval, (2019), available here.
60 Booten, C. et al., Refrigerants Market Trends and Supply Chain Assessment (Department of Energy, 2020), available here.
61 Based on Country Programme data published by the Secretariat of the Multilateral Fund and Article 7 data reported to the Ozone Secretariat. See: Multilateral Fund, 92nd Meeting of the Executive Committee, Country Programme Data and Prospects for Compliance (2022), See Table 2, available here. See also: Ozone Secretariat, Country Data, available here.
62 Represents the top reporters in the chemical sector facilities reporting emissions of fluorinated greenhouse gases under the U.S. Greenhouse Gas Reporting Program (GHGRP) and Toxic Release Inventory (TRI).
63 Science Direct, Beer-Lambert Law, available here.
64 The Calcment software's library contains reference spectra for over 400 gases. Additionally, EIA imported reference spectra for 43 other gases from Hitran, a spectroscopic database maintained by the Harvard-Smithsonian center for Astrophysics, available here. This library included all fluorinated gases reported by facilities, with the exception of HCFC-253fb, due to a lack of available reference spectrum for this gas.
65 Reference spectra sourced from the Gasmet library and HITRAN database. For full citations please see Supplementary Material, Annex 1, available here.
66 See Supplementary Material, Annex 2, available here.
67 U.S. Chemical Safety Board, "Investigation Report", (Washington, DC: U.S. CSB, (2005), 12, available here.
68 Booten, C. et al., "Refrigerants: Market Trends and Supply Chain Assessment, Clean Energy Manufacturing Analysis Center, (2020), available here.
69 Louisiana Department of Environmental Quality, Approval for Part 70 Permit Modification, (2020), available here.
70 Louisiana Department of Environmental Quality, Final Permit Approval, (2018), available here.
71 Louisiana Department of Environmental Quality, Final Permit Approval, (2019), available here.
72 Agresti, S., Honeywell Press Release, Honeywell Starts Increased Production At Baton Rouge Facility For Ultra-Low-Global-Warming-Potential Solution, (December 2022), available here.
73 Public Notice, Louisiana Department of Environmental Quality (LDEQ), Honeywell, Baton Rouge Plant, Proposed Part 70 Air Permit Renewal and Modification, (2020), available here.
74 EPA, TRI Facility Report for Honeywell International Inc-Baton Rouge Plants, available here.
75 Honeywell, "Honeywell Expands Baton Rouge Facility to Drive Growth of Low Global Warming Technologies", (November 17, 2021), available here.
76 Louisiana Department of Environmental Quality, Approval for Part 70 Permit Modification, (2020), available here.
77 Compiled by EIA from US Greenhouse Gas Reporting Data and Toxic Release Inventory
78 Booten, C. et al., "Refrigerants: Market Trends and Supply Chain Assessment, Clean Energy Manufacturing Analysis Center, (2020), available here.
79 EIA analysis of data reported to EPA, Toxics Release Inventory.
80 Technical Review: Air Permit by Rule, Chemours Ingleside Plant, Permit No 160883 (2020).
81 Area Development, Chemours Company Builds Refrigerant Plant In Ingleside, Texas, (2017), available here.
82 NOAA Chemical Sciences Library, HCFC datasets, (January 2018), available here.
83 The lowest detection limit (LDL) was calculated for each detected gas using the equation LDL=noise*3*ppm/Absorbance Unit, according to the method described in the Calcmet Expert manual.
84 100-year GWPs from IPCC Assessment Report 6, Chapter 7, (2021), available here.
85 Montzka, S. A., et al., "An unexpected and persistent increase in global emissions of ozone-depleting CFC-11", Nature 557.7705 (2018): 413-417, available here.
86 Rigby, M., et al., "Increase in CFC-11 emissions from eastern China based on atmospheric observations", Nature, 569.7757 (2019): 546-550, available here.
87 EIA, "Blowing It: Illegal Production and Use of Banned CFC-11 in China's Foam Blowing Industry", (2018), available here.
88 Tratt, D. M., et al., "Identification and source attribution of halocarbon emitters with longwave-infrared spectral imaging", Remote Sensing of Environment, 258 (2021): 112398, available here; See also Buckland, K. N., et al., "Tracking and quantification of gaseous chemical plumes from anthropogenic emission sources within the Los Angeles Basin", Remote Sensing of Environment, 201 (2017): 275-296, available here.
89 WMO, 2022
90 MCTOC, 2022
91 WMO, 2022
92 MCTOC, 2022
93 WMO, 2022
94 Ibid.
95 MCTOC, 2022
96 ExCom/91/71 Report of the Sub-Group on the Production Sector (December 2022)
97 WMO, 2022
98 Ibid., See Figure 7-3.
99 Article 7 Data Reporting on US HCFC Production, available here.
100 Louisiana Department of Environmental Quality, Final Permit Approval, (2019), available here.
101 Booten, C. et al., Refrigerants Market Trends and Supply Chain Assessment (Department of Energy, 2020), available here.
102 2023 TEAP Progress Report Volume 1, available here.
103 TEAP May 2023 Progress Report - Volume 1, Section 5.3.3, available here.
104 United Nations Environment Program: Ozone Secretariat, Handbook to the Montreal Protocol on Substances that Deplete the Ozone Layer, (14th Edition, 2020), Article 7 on data reporting, available here.
105 Decision IV/12 of Parties to the Montreal Protocol: Clarification of the definition of controlled substances, available here.
106 TEAP 2021 Progress Report, see p8, available here.
107 EPA, Draft regulatory Analysis for Phasing Down HFCs, Chapter 6: Environmental Justice Analysis, See Table 6-3, available here.
108 MCTOC, 2022
109 Ibid.
110 WMO, 2022
111 MCTOC, 2022: See Tables 2.6 and 2.7
112 Ibid., See Table ES1
113 Ibid., See Tables 2.7 and 2.8
114 Emissions and average GWP of 1663 derived from MCTOC, 2022: Table 2.9
115 Applies emissions factors from MCTOC, 2022: Tables 2.7 and 2.8
116 MCTOC, 2022 and TEAP 2023 Progress Report

environmental investigation agency

EIA US: PO Box 53343, Washington, D.C. 20009
EIA UK: 62-63 Upper Street, London N1 0NY UK

us.eia.org
EnvironmentalInvestigationAgencyUS
EIAEnvironment
EIAEnvironment